UMTA-MA-06-0153-85-9
DOT-TSC-UMTA-86-11

Department
of Transportation

Urban Mass Transportation Administration

Inductive Interference in Rapid Transit Signaling Systems

Volume III: Data and Test Results

F. Ross Holmstrom

Transportation Systems Center
Cambridge, MA 02142

November 1986
Final Report

UMTA Technical Assistance Program

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTA-MA-06-0153-85-9		

4. Title and Subtitle	5. Report Date
INDUCTIVE INTERFERENCE IN RAPID TRANSIT SIGNALING SYSTEMS, VOLUME III: DATA AND TEST RESULTS	November 1986
	6. Performing Organization Code DTS-77
7. Author(s) F. Ross Holmstrom	8. Performing Organization Report No. DOT-TSC-UMTA-86-11
9. Performing Organization Name and Address U.S. Department of Transportation Research and Special Programs Administration Transportation Systems Center Cambridge, MA 02142	10. Work Unit No. (TRAIS) UM676/U6601 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Urban Mass Transportation Administration Office of Technical Assistance Washington, DC 20590	13. Type of Report and Period Covered April 1979 - Sep 1985 14. Sponsoring Agency Code URT-12

15. Supplementary Notes

16. Abstract

This report presents comparative inductive interference data obtained from four U.S. rapid transit systems employing chopper propulsion control. Chopper propulsion control is standard at three of these systems: Bay Area Rapid Transit District (BART), Metropolitan Atlanta Rapid Transit Authority (MARTA), and Greater Cleveland Regional Transit Authority (GCRTA). The fourth system, New York City Transit Authority (NYCTA), conducted operational tests of a prototype chopper propulsion system. The four propulsion systems were designed and manufactured by four different suppliers. The theory of inductive interference generation in rapid transit signaling systems, on which a full understanding of these data is based, has been presented in an earlier report in this series.

17. Key Words	18. Distribution Statement
Rapid Transit, Signaling, EMI, Choppers	DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	44	

Form DOT F1700.7 (8-72) Reproduction of completed page authorized

Technical Report Documentation Page

1. Report No. UMTA-MA-06-0153-85-9	2. Government Accession No. PB87-170007/AS	3. Recipient's Catalog No.
4. Title and Subtitle Inductive Interference in Rapid Transit Signaling Systems. Volume III: Data and Test Results.		5. Report Date November 1986
		6. Performing Organization Code DTS-77
7. Author's) F. Ross Holmstrom		8. Performing Organization Report No. DOT-TSC-UMTA-86-11
9. Performing Organization Name and Address U.S. Department of Transportation Research & Special Programs Administration Transportation Systems Center Cambridge, Massachusetts 02142		10. Work Unit No. (TRAIS) MA-06-0153(UM676/U6601)
		11. Contract or Grant No. MA-06-0153
12. Sponsoring Agency Name and Address U.S. Department of Transportation Urban Mass Transportation Administration 400 Seventh Street, S.W. Washington, D.C. 20590		13. Type of Report and Period Covered April 1979-Sept.1985
		14. Sponsoring Agency Code URT-12
15. Supplementary Notes		

16. Abstract

This report presents comparative inductive interference data obtained from four U.S. rapid transit systems employing chopper propulsion control, as part of the Rail Transit Electromagnetic Interference/Electromagnetic Compatibility program conducted by the Transportation Systems Center in Cambridge, Massachusetts. Chopper propulsion control is standard at three of the systems: Bay Area Rapid Transit District (BART); Metropolitan Atlanta Rapid Transit Authority (MARTA); and Greater Cleveland Regional Transit Authority (GCRTA). The fourth system, New York City Transit Authority (NYCTA), conducted operational tests of a prototype chopper propulsion system installed in a married pair of R-46 cars. The four propulsion systems were designed and manufactured by four different suppliers.

The theory of inductive interference generation in rapid transit signaling systems and discussion of the mechanisms involved, has been presented in an earlier report in this series: Inductive Interference in Rapid Transit Signaling Systems, Volume I: Theory and Background (NTIS Order Number PB 87-114427/AS, Price A03). That report provides the basis for analyzing the supplementary data presented here. Suggested test procedures for observing, recording and analyzing inductive interference signals have been presented in a second report: Inductive Interference in Rapid Transit Signaling, Volume II: Suggested Test Procedures, which has not been entered into the NTIS system at this time.

17. Key Words BART; Comparative Inductive Interference; Electromagnetic Compatibility; Electromagnetic Interference; GCRTA; Inductive Interference; MARTA; NYCTA; Propulsion Systems; Signaling; Rapid Rail Transit		18. Distribution Statement This report is available to the public through the National Technical Information Service in Springfield, Virginia 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 40	22. Price A03

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The purpose of this report is to present comparative inductive interference data that were obtained from four rapid transit systems as part of the rail transit EMI/EMC program conducted by DOT/TSC. Data from three systems previously were presented to the Rail Transit EMI/EMC Technical Working Group in a June 1980 talk by F.R. Holmstrom, "Comparisons of Inductive Chopper Interference from MARTA, BART, and NYCTA." Data from the fourth system are from DOT Report No. DOT-TSC-UM204-PM-82-11 by Robert Gagnon, "Cleveland Inductive Emissions Tests (Sept. 23-25, 1981)," dated April 1982.

The theory of inductive interference generation and its effects on rapid transit signaling systems have been discussed in a prior report [Ref. 1]. Another prior report [Ref. 2] outlines suggested test procedures for observing and measuring inductive interference and its effects. The data presented in this report have been used extensively in developing an understanding of inductive interference and how to mitigate its effects.

Many people contributed to the efforts to gather the data presented in this report. The personnel of the Bay Area Rapid Transit District, New York City Transit Authority, Metropolitan Atlanta Rapid Transit Authority, and Greater Cleveland Rail Transit Authority were most helpful and forthcoming in undertaking the joint efforts to gather these data. Personnel of the propulsion suppliers - Westinghouse Electric, General Electric, Garrett, and Brown-Boveri Canada - took part in the testing of their respective systems, and provided timely information concerning the characteristics of their propulsion systems. In addition to the author, the following DOT/TSC and contractor personnel were involved directly in these tests: Louis A. Frasco, Robert Gagnon, Eugene T. Leonard, and Norka Shedlock.

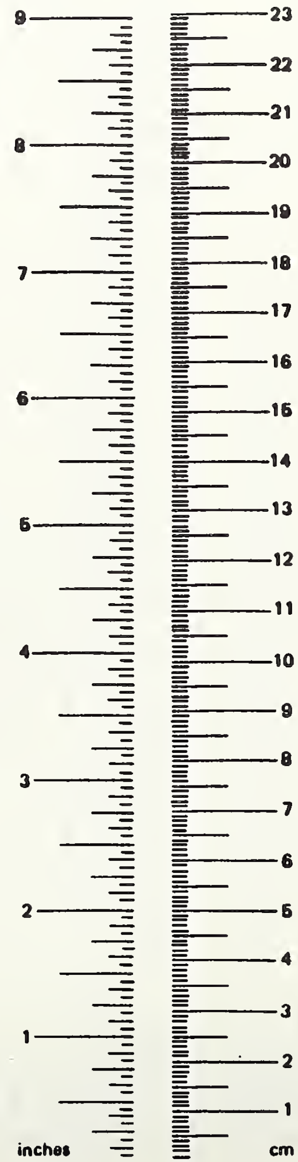
This work was performed as part of the rail transit EMI/EMC program of the UMTA Office of Systems Engineering, under the direction of Ronald Kangas, Chief of the Design Division.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

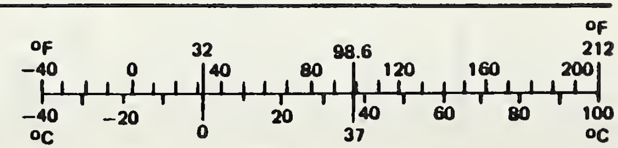


TABLE OF CONTENTS

FIGURES

EXECUTIVE SUMMARY

This report presents comparative inductive interference data obtained from four rapid transit systems. Chopper propulsion control is standard at three of these systems: Bay Area Rapid Transit District, Metropolitan Atlanta Rapid Transit Authority, and Greater Cleveland Rapid Transit Authority. The fourth system, the New York City Transit Authority, conducted operational tests of a prototype chopper vehicle.

The four propulsion systems were designed and manufactured by four different suppliers - Westinghouse Electric, Garrett, Brown-Boveri Canada, and General Electric, respectively. In spite of greatly differing designs, the inductive interference characteristics of the four types of propulsion control systems were qualitatively similar.

The data in this report supplement the more restricted data presented in prior reports of this series dealing with the theory of inductive interference and methods for its measurement and characterization [Ref's 1, 2].

1. INTRODUCTION

Inductive interference occurs in rapid transit signaling systems when time-varying magnetic flux lines emanating from solid-state propulsion control systems on vehicles pass through the rail-axle loops under the cars. When a rapid transit car passes over a point at which an audio-frequency track circuit receiver is connected to the rails, interfering signals generated by the audio-frequency harmonics of the stray flux can cause the track circuit to malfunction.

The theory of inductive interference generation in rapid transit signaling systems, and discussion of the mechanisms involved, have been presented in an earlier report in this series, "Inductive Interference in Rapid Transit Signaling Systems - Volume I: Theory and Data" [Ref. 1]. That report provides the basis for analyzing the supplementary data presented here. Suggested test procedures for observing, recording, and analyzing inductive interference signals have been presented in a second report, "Inductive Interference in Rapid Transit Signaling Systems - Volume II: Suggested Test Procedures" [Ref. 2]. Data presented in this report were gathered by direct application of Method RT/IE01A described in Volume II.

The purpose of this report is to present comparative inductive interference data obtained from four different rapid transit systems employing chopper propulsion control. Chopper propulsion control is standard at three of these systems: Bay Area Rapid Transit District (BART), Metropolitan Atlanta Rapid Transit Authority (MARTA), and Greater Cleveland Regional Transit Authority (GCRTA). The fourth system, New York City Transit Authority (NYCTA), conducted operational tests of a prototype chopper propulsion system installed in a married pair of R-46 cars.

The four propulsion systems were designed and manufactured by four different suppliers. BART cars have propulsion systems designed and built by Westinghouse Electric Corporation; MARTA by Garrett Corporation; GCRTA by BBC Canada, Ltd. (BBC); and the NYCTA chopper propulsion system by General Electric. While differing in their circuitry and operation in major respects, the four propulsion systems were similar in their means of operation. Each

employed thyristors as series on-off switches, switched at a rate of several hundred Hz, to control the short-time average motor voltage applied to the dc traction motors. In each case, forced commutation by means of a resonant LC circuit was used to turn the series thyristors off at the end of a conduction pulse.

The future will see the introduction in the U.S. of rapid transit propulsion systems employing solid state inverters to furnish polyphase power to ac traction motors. Such "ac drive" systems will differ in their inductive interference characteristics from the "chopper" systems discussed in this report. However, it is believed that the same analytical and experimental techniques will be used to evaluate the characterics of inductive interference of such systems.

The reader must avoid the temptation to declare any of the systems reported on here as "better" or "worse" on the basis of the data presented in this report. Electromagnetic interference (EMI) involves an interplay of sources of emission and affected systems. The effects of inductive interference depend on the specific characteristics of the audio-frequency signaling systems involved, as well as the EMI generation characteristics of the propulsion systems. Achieving electromagnetic compatibility (EMC) in rapid transit applications requires coordinated effort in the development of signaling systems and propulsion systems. Without coordination, EMC may be possible only by unacceptably expensive over-design of both propulsion and signaling systems.

2. INDUCTIVE INTERFERENCE GENERATION: A SYNOPSIS

Figure 1 shows the configuration of car and signaling equipment that leads to inductive chopper interference. Pulsed magnetic flux from inductors, other components, and cables in the propulsion system passes downward through the closed loops formed by the rails, car axles, and impedance bond leads. The time-variation of the magnetic fluxes Φ_1 and Φ_2 produces interference voltage between the rail leads of the signaling system.

Figure 2 shows a simplified diagram of a typical rapid-transit chopper operating in the propulsion mode. A chopper is an electronically controlled on-off switch. The switch is pulsed on and off at a repetition rate of a few hundred Hz, and delivery of electrical power to the traction motors is controlled by varying the fraction of time the switch is on. A brief description of chopper operation is presented here.

Prior to gating on the main thyristor T_M, the commutation capacitor C_C is charged to the dc line voltage V_L by transient current flowing from the third rail through L_L, C_C, commutation reactor L_C, commutation diode D_C, motor smoothing reactor L_M, and the motors. The main thyristor T_M is gated on to initiate a motor power pulse. Since the voltage across T_M then becomes zero, the commutation thyristor T_C becomes forward-biased by amount V_L. Motor current then flows through T_M, L_M, and the motor.

To turn off voltage applied to L_M and the motors, T_C is gated on, thus transferring the voltage across T_C to L_C. A commutation current pulse then starts in the clockwise direction through the closed loop formed by C_C, T_M, T_C, and L_C. This pulse is a sinusoid with frequency $f_C = 1/[2\pi\sqrt{(L_C C_C)}]$, typically approximately 10 times the chopper repetition frequency. The commutation current pulse reverses polarity after the first quarter-cycle, and flows in the reverse direction through T_M, driving the total current through T_M to zero, allowing it to turn off. With T_M off, C_C once more charges as before, by current flow from C_L through C_C, L_C, D_C, and in the reverse direction through the free-wheeling diode D_F. (D_F is kept on in forward conduction by motor current that circulates around the D_F, L_M, motor loop after T_M turns off.)

GENERATION OF INDUCTIVE INTERFERENCE

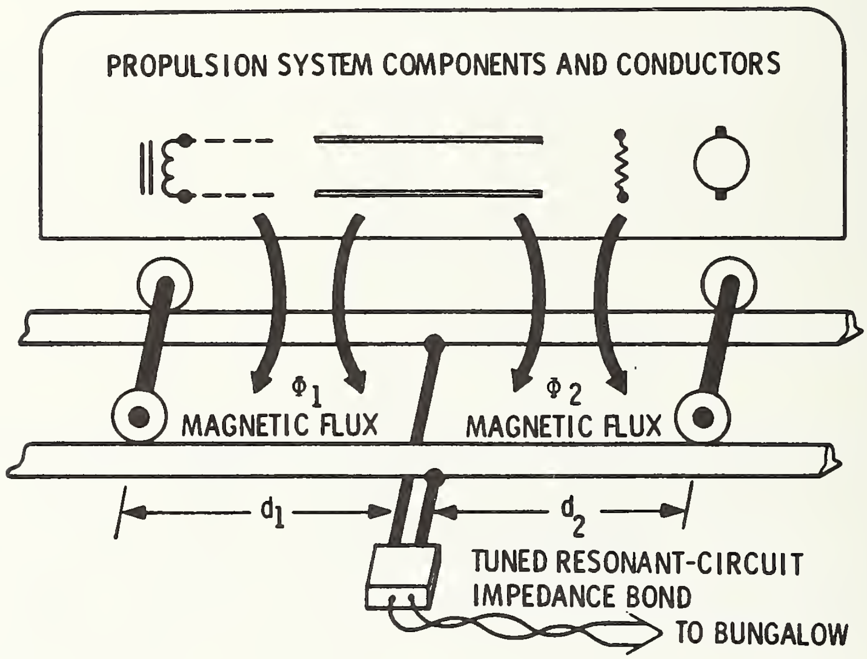


FIGURE 1. CONFIGURATION OF CAR AND SIGNALING EQUIPMENT LEADING TO INDUCTIVE CHOPPER INTERFERENCE.

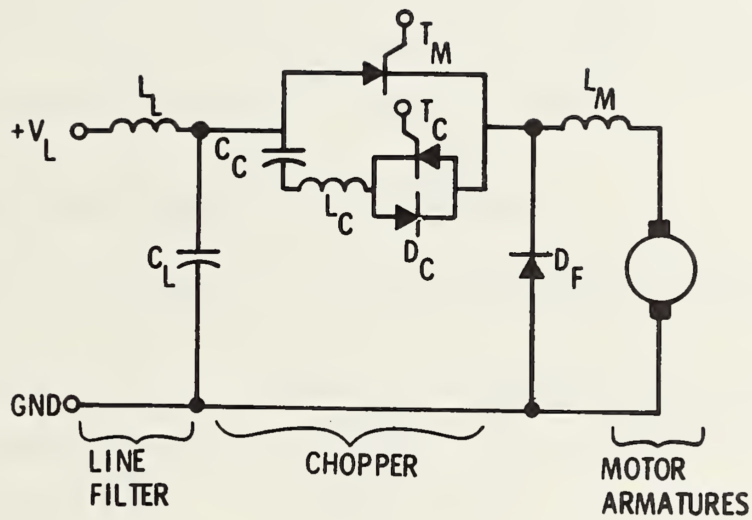


FIGURE 2. A CHOPPER CIRCUIT SHOWING WIRING FOR PROPULSION MODE.

Power feed to $+V_L$ is from third rail or catenary, and ground return is to running rails.

None of the four chopper systems tested employed a circuit exactly like that shown in Figure 2. However, each used equivalent components arranged in a circuit that had similar overall operating characteristics. The preponderant sources of stray magnetic flux in the four systems tested were the reactors L_L, L_C, and L_M. Flux from these components provided the greatest contribution to audio-frequency harmonic signals observed.

3. MEASUREMENT AND DATA

3.1 Measurement Procedures

Inductive interference data were gathered using the procedures outlined in Method RT/IE01A (see Appendix). Figure RT/IE01A-1 in the Appendix shows a schematic diagram of the test set-up used for collection of inductive interference data. The data consist of audio-frequency tape recordings of open-circuit rail-to-rail voltage occurring as a rapid transit train passes, oscilloscope photos of voltage waveform, and FFT spectrum analyzer plots of harmonic spectra. Voltage waveform photos and spectrum analyzer plots were made both "live" and from played-back tape recordings.

3.2 Comparisons of Car Component Characteristics

The following table summarizes salient characteristics of the cars tested.

MARTA -	Commutation reactor:	Air-core solenoid, vertical axis
	Motor smoothing reactor:	Air-core solenoid, vertical axis
	Chopper enclosure:	Fiberglass doors
	Line voltage:	900 volts
BART -	Commutation reactor:	Air-core solenoid, longitudinal axis
	Motor smoothing reactor:	Iron-core solenoid, vertical axis
	Chopper enclosure:	Steel doors
	Line voltage:	1000 volts
NYCTA -	Commutation reactor:	Air-core solenoid, transverse axis
	Motor smoothing reactor:	Iron H-core with cross on H transverse
	Chopper enclosure:	Aluminum doors
	Line voltage:	600 volts
GCRTA -	Commutation reactor:	Air-core toroid
	Motor smoothing reactor:	Iron-core solenoid, transverse axis
	Chopper enclosure:	Steel doors
	Line voltage:	600 volts

3.3 MARTA Data

Figure 3 shows an oscilloscope photo of rail-to-rail voltage made during the passage of a MARTA car past the observation point. The photo represents interference voltage at a time near peak harmonic generation during a maximum-acceleration run. This photo was made by playing the tape recorded signal back into an oscilloscope. The amplitude scale was calibrated by use of a recorded signal of known level. The photo shows two complete on-off cycles. The photo begins with T_M off for 1.3 msec. Then, T_M turns on and a tilted rectangular pulse of 0.8 msec duration follows. This pulse is proportional in amplitude to the voltage across L_M. Commutation results in a voltage spike swinging downward, then upward, as voltage across L_C occurs first with one sign and then the other. The cycle ends with a 0.4 msec triangular ramp as C_C charging current flows.

Figure 4 shows a typical Fast Fourier Transform (FFT) spectral plot for a MARTA car as a train passes while accelerating. Each spectral plot is calculated from 1024 data samples taken within a single 40 msec sampling time window. Harmonic lines occur at integral multiples of the 400 Hz MARTA chopper frequency.

Figure 5 shows the strength of a single harmonic line vs. time as a four-car MARTA train accelerates past a fixed measuring point. The line pictured is the ninth harmonic at 3600 Hz. Each car contributes one of the four bursts of harmonic seen in Fig. 5. The amplitude behavior vs. time of each burst is influenced by the following factors: Distance from the measuring point to the nearest interior axle, since axles provide a shorting path for induced currents; the time-varying chopper conduction angle, of which harmonic strength is a function; and motor current, which decreases as the train nears maximum speed. (See Ref. 1 for a detailed analysis of harmonic behavior.)

3.4 BART Data

Figure 6 shows the rail-to-rail voltage near the time of peak interference production as the third car of a four-car BART train accelerates past the

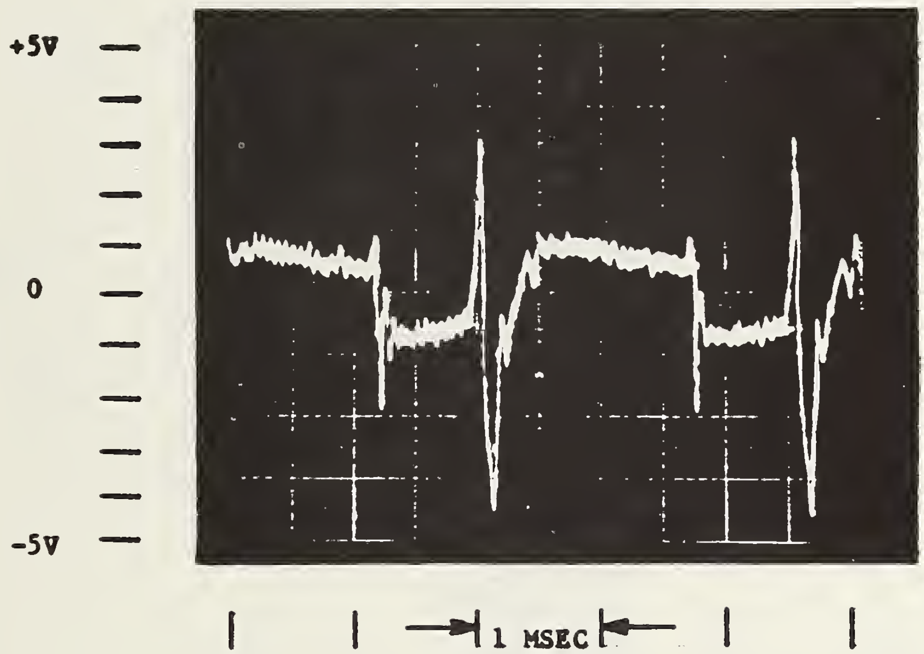


FIGURE 3. RAIL-TO-RAIL INDUCTIVE INTERFERENCE VOLTAGE VS. TIME FOR A MARTA CAR.

Oscilloscope photo was made from tape recording during peak acceleration run.

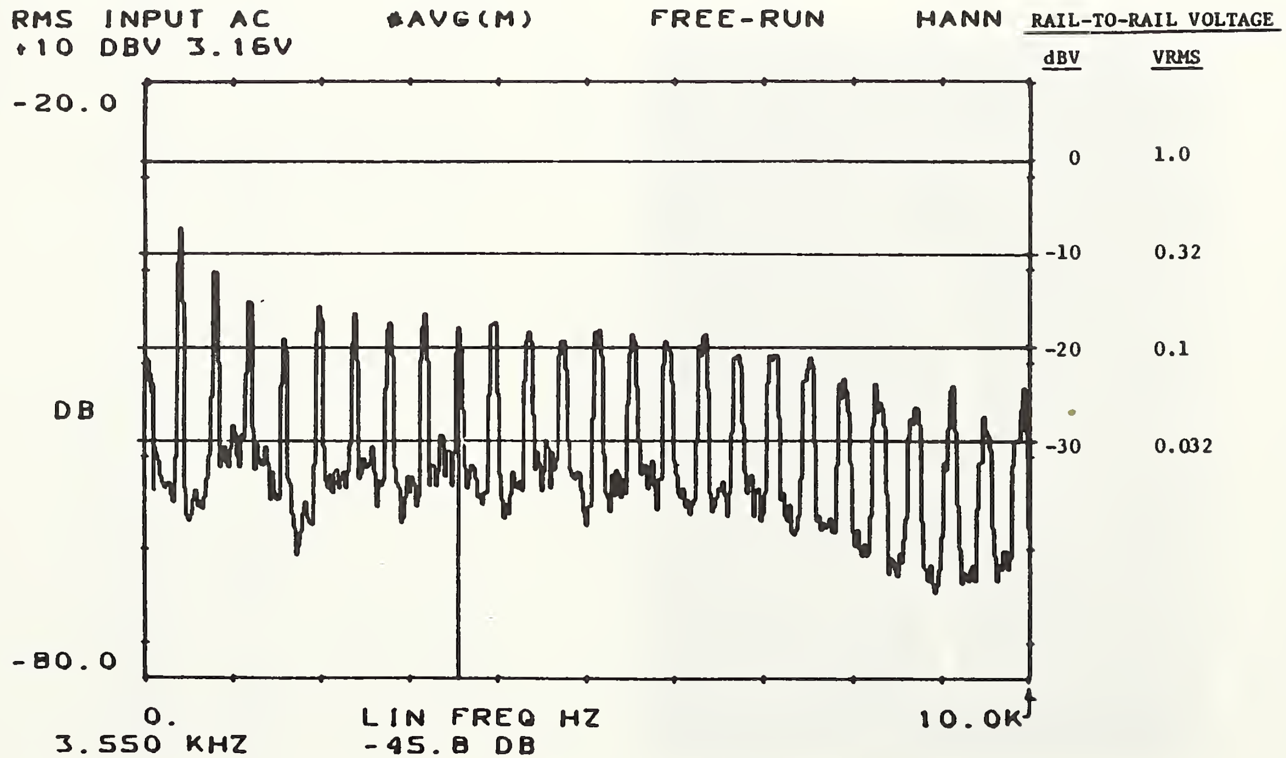


FIGURE 4. FFT SPECTRAL PLOT OF INDUCTIVE INTERFERENCE FOR A MARTA CAR.

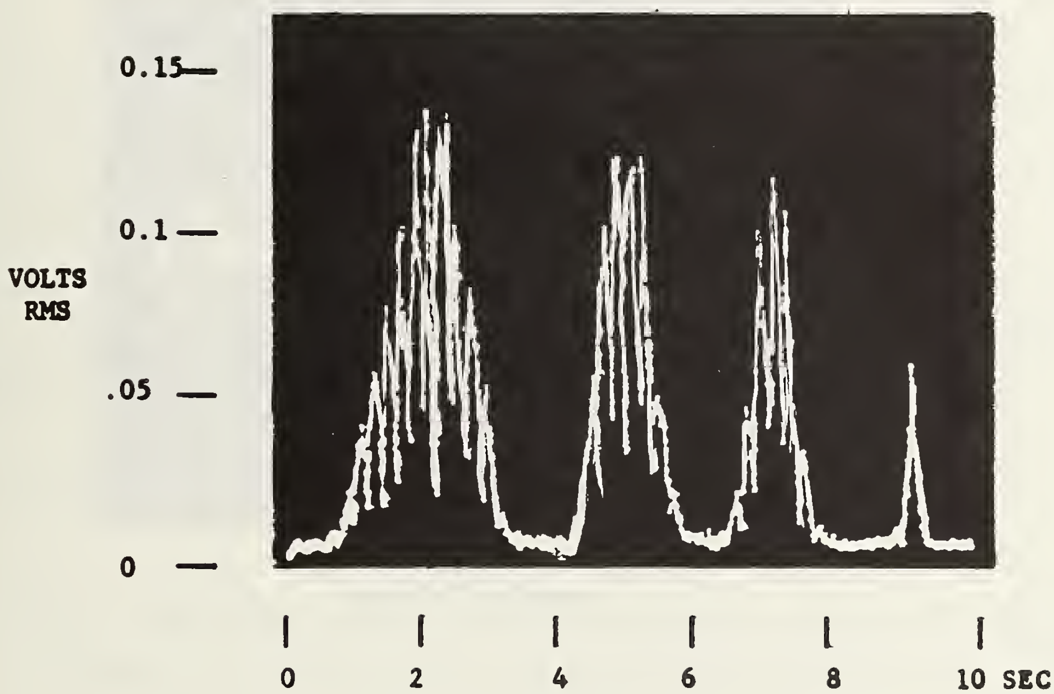


FIGURE 5. AMPLITUDE OF THE INDUCTIVE INTERFERENCE HARMONIC AT 3600 HZ VS. TIME FOR A MARTA TRAIN.

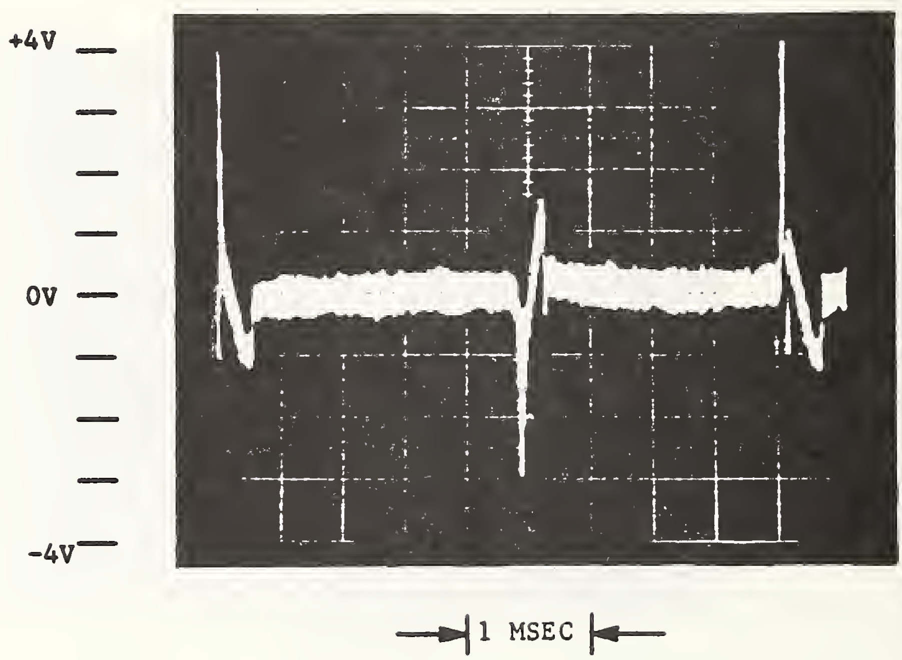


FIGURE 6. RAIL-TO-RAIL INDUCTIVE INTERFERENCE VOLTAGE VS. TIME FOR A BART CAR.

measuring point. The commutation reactor provides the major observable contribution to interference. Figure 7 shows a typical FFT spectral plot for a BART train. Harmonic lines occur at harmonics of the 218 Hz BART chopper frequency. The broad spectral peaks at approximately 7700 Hz and 8700 Hz are modulation-broadened track signals that were present when the inductive interference data were taken.

Figure 8 shows the strength of the 12th harmonic of rail-to-rail voltage at 2616 Hz observed as a train accelerates past the measuring point. Here, a single burst of harmonic is seen to occur as the commutation reactor of each car passes the measuring point. Since the commutation reactors of BART cars are longitudinally oriented, net flux encircles the rail lead running between the rails only when the commutation reactor is practically directly over the lead. Thus, one burst of harmonic is recorded with the passage immediately overhead of the commutation reactor of each of the four cars.

3.5 NYCTA Data

Figure 9 shows the rail-to-rail voltage near the time of peak interference production of the first car of the experimental two-car NYCTA train, observed as the train accelerates past the mesuring point. Figure 10 shows a corresponding typical FFT spectral plot, and Figure 11 shows the strength of the tenth chopper harmonic at 3000 Hz as the train accelerates past the measuring point.

3.6 GCRTA Data

Figure 12 shows a typical FFT spectral plot for a GCRTA train. Harmonic lines occur at harmonics of the 440 Hz GCRTA chopper frequency.

3.7 Composite Worst-Case Data

In performing the tests described above, many individual runs were made at each transit system, with cars accelerating from rest at various power levels. Trains were started from rest at varying distances from the measuring point,

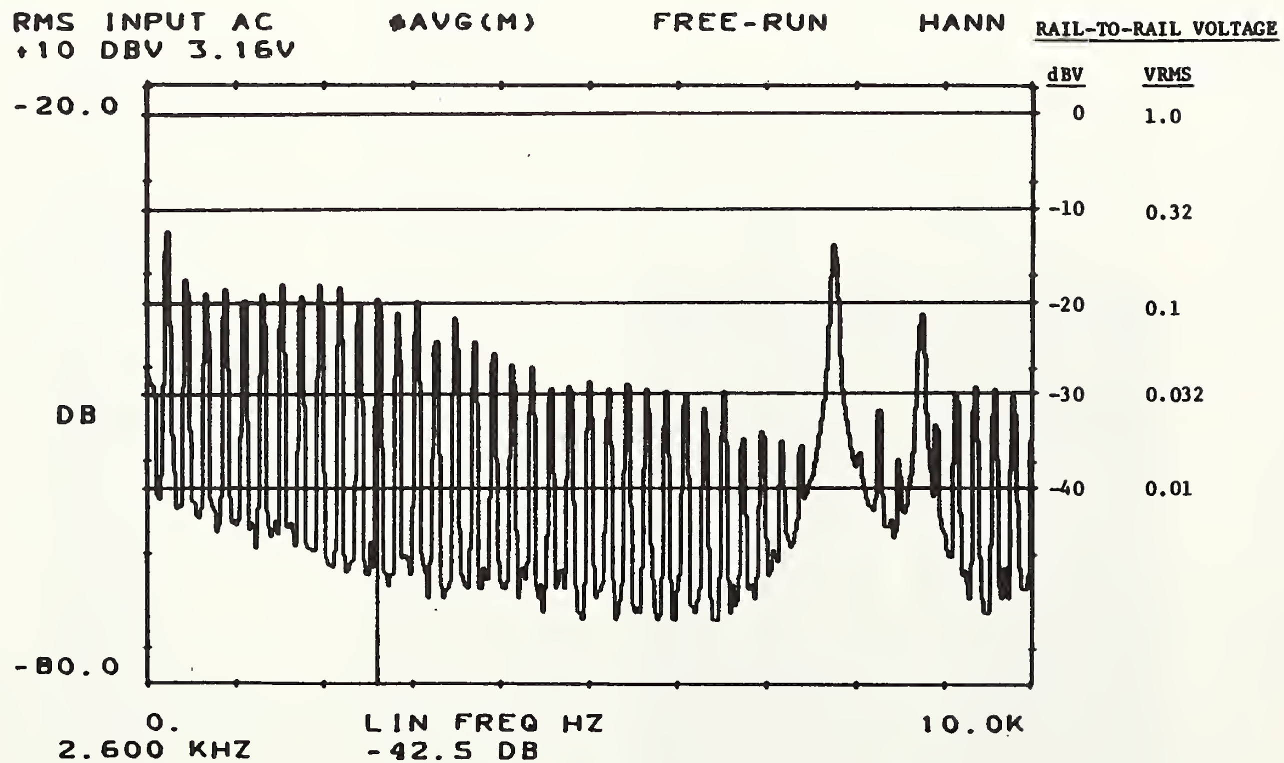


FIGURE 7. FFT SPECTRAL PLOT OF INDUCTIVE INTERFERENCE FOR A BART TRAIN.

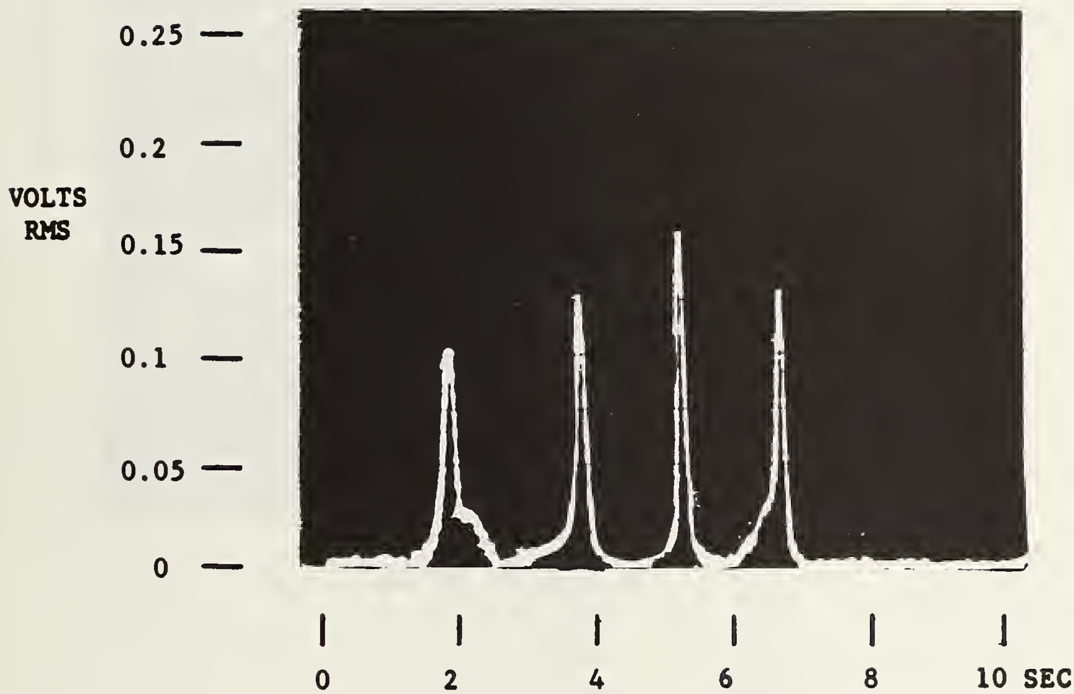


FIGURE 8. AMPLITUDE OF THE INDUCTIVE INTERFERENCE HARMONIC AT 2616 HZ VS. TIME FOR A BART TRAIN.

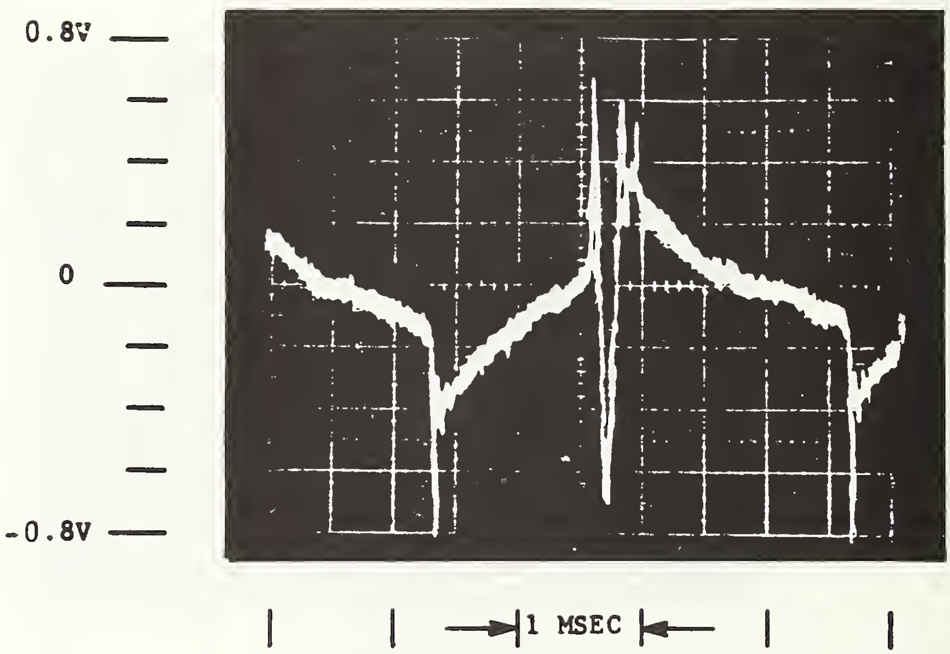


FIGURE 9. RAIL-TO-RAIL INDUCTIVE INTERFERENCE VOLTAGE VS. TIME FOR A NYCTA CAR.

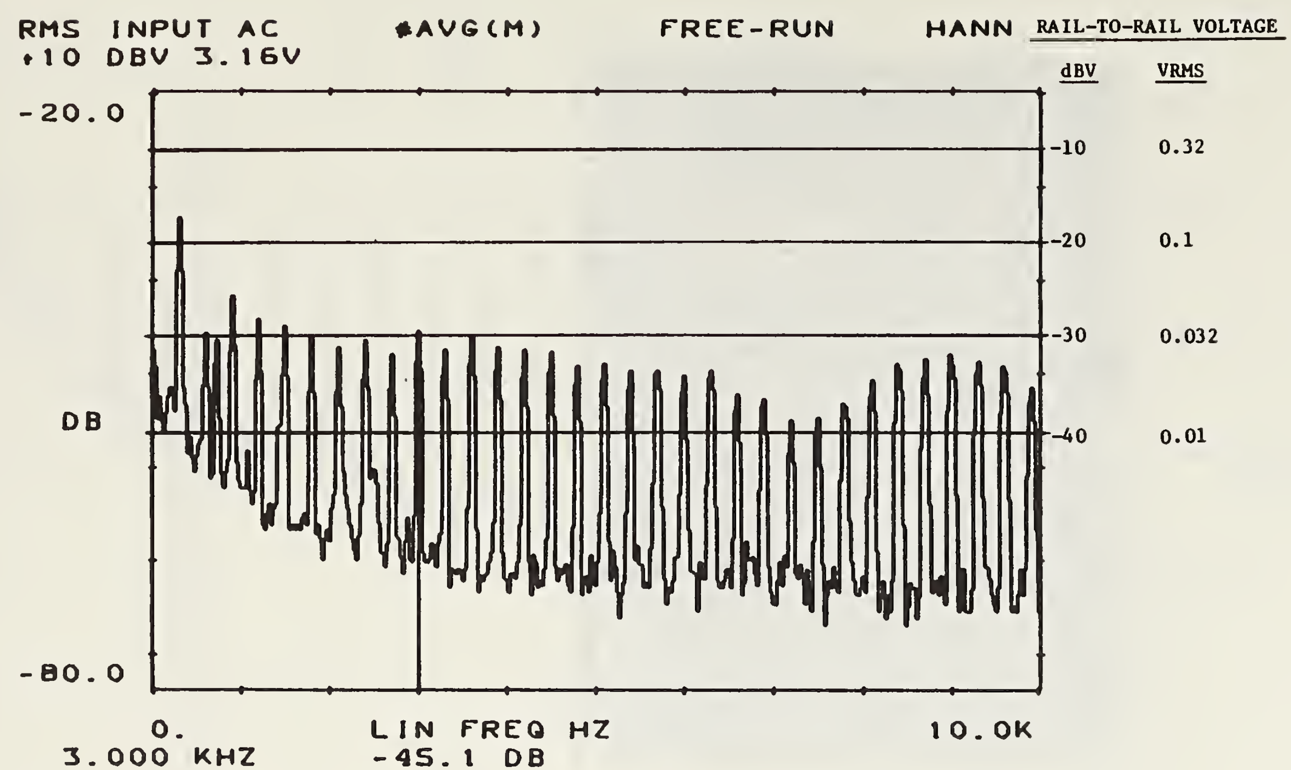


FIGURE 10. FFT SPECTRAL PLOT OF INDUCTIVE INTERFERENCE FOR A NYCTA TRAIN.

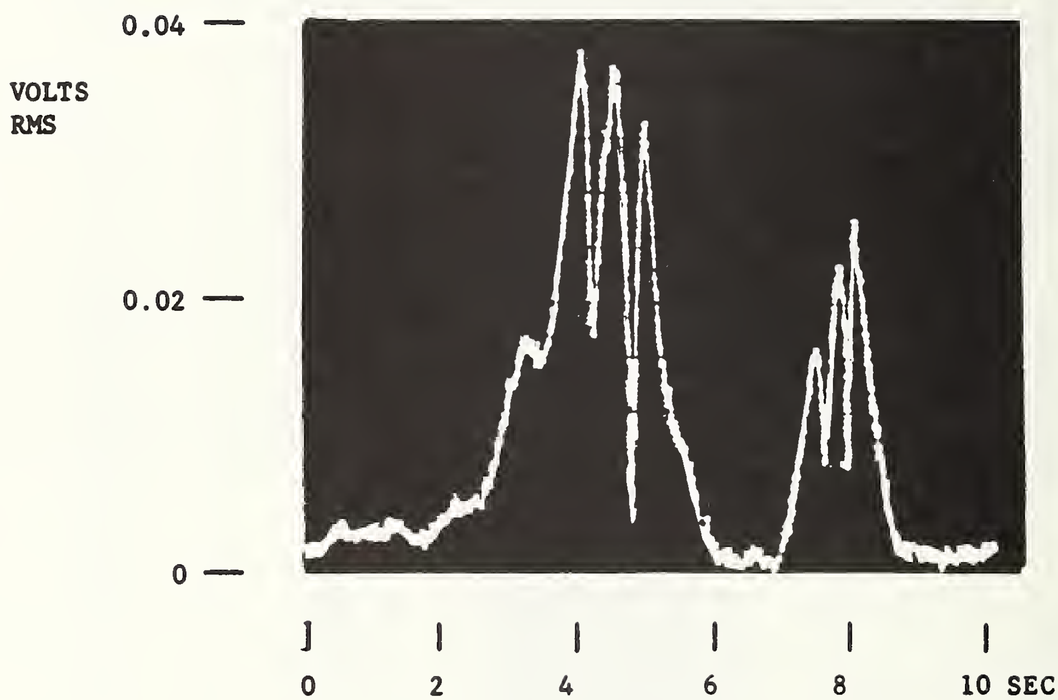


FIGURE 11. AMPLITUDE OF THE INDUCTIVE INTERFERENCE HARMONIC AT 3000 HZ VS. TIME FOR A NYCTA TRAIN.

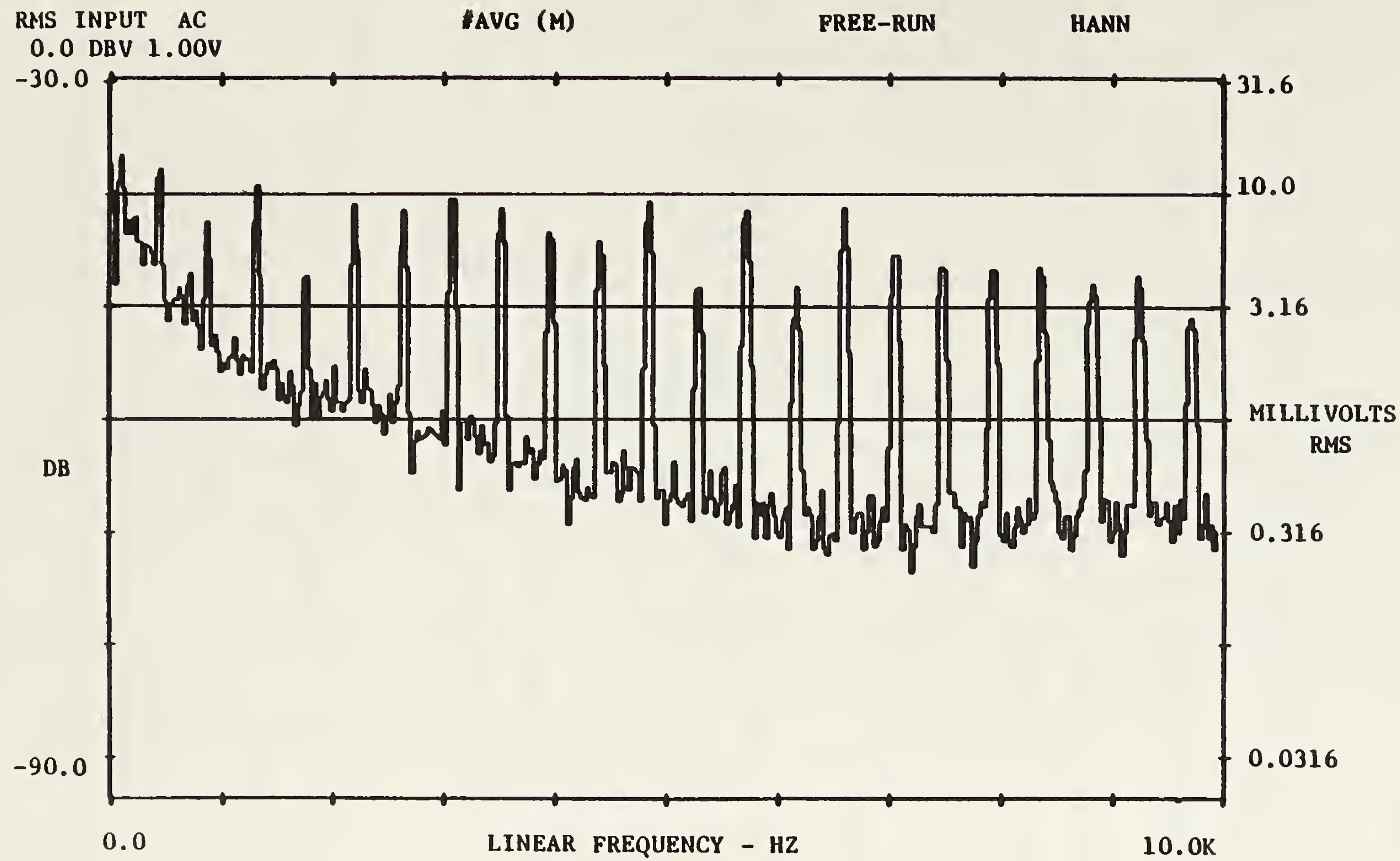


FIGURE 12. FFT SPECTRAL PLOT OF INDUCTIVE INTERFERENCE FOR A GCRTA TRAIN.

to allow observation of rail-to-rail harmonic voltage as cars passed the measuring point at a variety of speeds. Measurements were also made during regenerative braking.

As seen in Figures 5, 8, and 11 above, the strength of each chopper harmonic line varies as a function of time. In general, the time variation of the amplitude of each harmonic is different. For each transit system, 20 to 30 FFT plots similar to Figures 4, 7, 10, and 12 were recorded.

For each of the transit systems examined, a worst-case inductive interference envelope was determined. Each worst-case envelope was constructed by graphically transferring the harmonic amplitude data from each plot from a given property to a single composite plot. Then, for each transit system's composite plot, a curve was drawn through the peaks. The worst-case envelopes are shown in Figure 13.

A worst-case envelope serves as a very gross measure of possible inductive interference of a given propulsion system with signaling systems. If the worst-case envelope falls below the sensitivity levels of track circuit receivers, then inductive interference will not occur. However, neither will inductive interference occur if signal frequencies are placed in the notches between a propulsion system's harmonic spectral lines, and the spectral lines always remain stable in frequency. Nor will inductive interference occur if individual bursts of interference are of sufficiently short duration.

Consideration of a propulsion system's worst-case inductive interference envelope, together with a signaling system's receiver sensitivities, will provide some indication of the efforts that will be required to achieve compatibility between the two. The data in Figure 13 are presented to privide an indication of how inductive interference generation is related to choice and placement of propulsion system components. These data do <u>not</u> answer the question of best overall design of compatible propulsion and signaling systems.

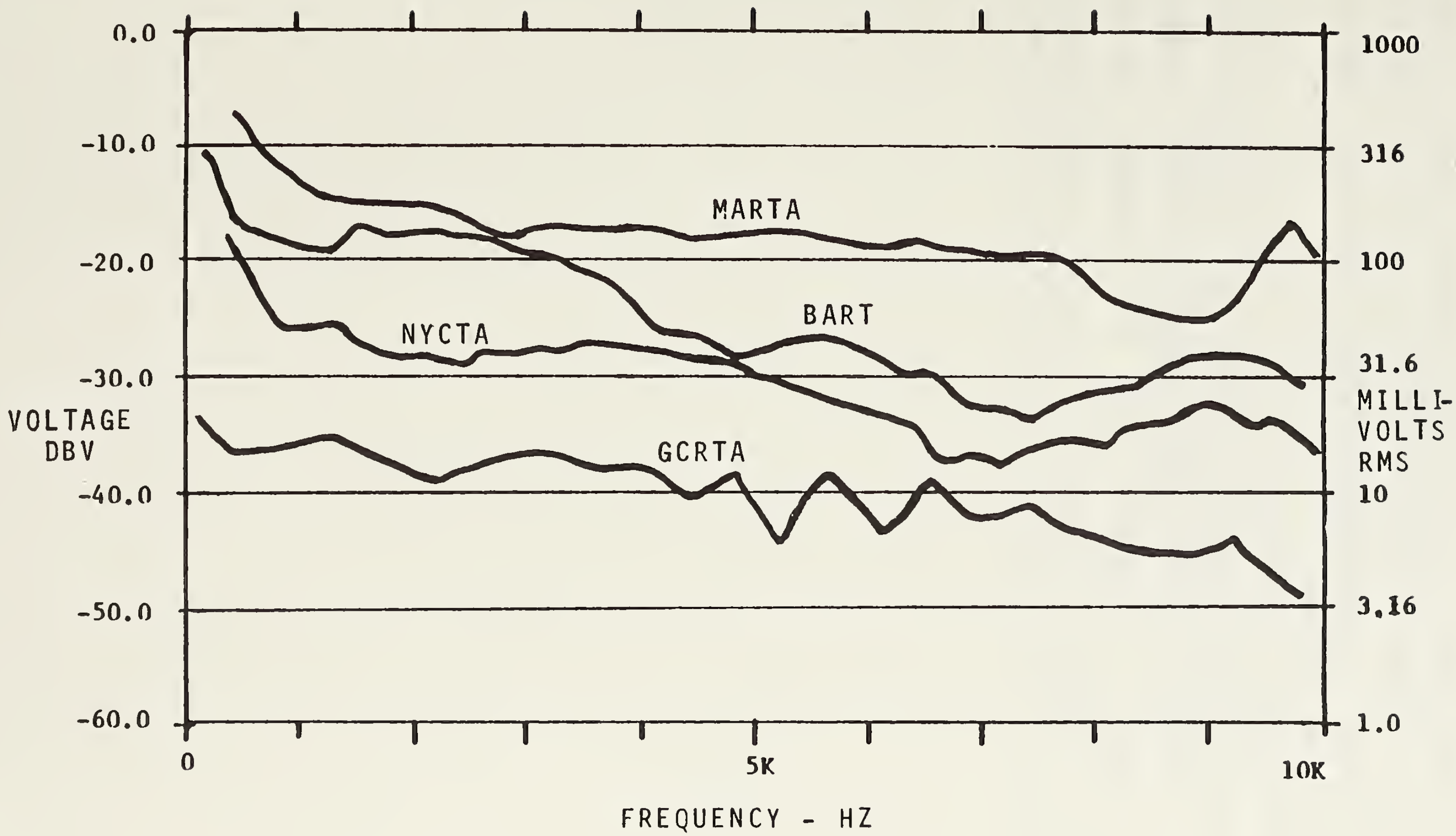


FIGURE 13. WORST-CASE INDUCTIVE INTERFERENCE ENVELOPES FOR MARTA, BART, NYCTA, AND GCRTA.

4. SUMMARY & CONCLUSIONS

Inductive interference data have been presented from four rapid transit systems employing chopper propulsion control. Although specific chopper circuit and component characteristics varied greatly, the four systems had qualitatively similar behavior.

The information presented here is not intended to provide direct answers to problems of designing future chopper propulsion control systems. It is intended to provide a reference point for assessing EMI performance characteristics of chopper systems, and to provide a qualitative picture of expected results from future inductive interference testing programs.

APPENDIX

METHOD RT/IE01A

INDUCTIVE EMISSIONS OF VEHICULAR ELECTRICAL POWER SUBSYSTEM

RAIL-TO-RAIL VOLTAGE FROM 20 HZ TO 20 KHZ

METHOD RT/IE01A

INDUCTIVE EMISSIONS OF VEHICULR ELECTRICAL POWER SUBSYSTEM, RAIL-TO-RAIL VOLTAGE FROM 20 Hz TO 20 kHz

1. PURPOSE

This method is used for measuring amplitudes of the harmonic components of interference voltage from 20 Hz to 20 kHz, measured from rail to rail during the passage of a rail transit vehicle.

2. APPLICABILITY

The test is intended primarily for rail transit vehicles equipped with chopper propulsion control systems, but may be performed for other types of rail transit vehicles as well, where applicable. Inductive interference is caused by the time-varying magnetic flux lines emanating from propulsion equipment and other electrical equipment on the vehicle passing through the rail-axle loop under the vehicle. Its presence is evidenced by the observation of abnormally high levels of rail-to-rail voltage observed at locations under the vehicle. The passage of a vehicle over a fixed location induces a transient interference voltage from rail to rail, the harmonics of which can have measurable amplitude throughout the audio-frequency spectrum. The induced voltages can be coupled into audio-frequency track circuit apparatus and disrupt the normal operation of such equipment. The procedure described below has been applied successfully and an example of the results is presented in Appendix B. [Note: See Appendix B of Ref. 1, pg. 33 of this report.]

3. TEST APPARATUS

Test apparatus shall consist of the following:

a. GenRad Model 2512 spectrum analyzer, or equal (FFT spectrum analyzer capable of real-time spectral analysis at 20 kHz, with 400 evenly spaced frequency increments from 0 Hz to maximum of range used).

b. Oscilloscope camera for spectrum analyzer (optional).

c. Tape recorder, Brüel and Kjaer Model 7005 with Direct Record Unit ZE-0299, or equivalent (IRIG Intermediate Band, Direct Record, 15 in/sec, with at least two channels).

d. X-Y plotter, Esterline-Angus Model XY575, or equal, compatible with spectrum analyzer.

e. Audio-frequency signal generator.

f. True RMS voltmeter.

g. Track coupling network consisting of isolation transformer, 1:1 (UTC Model LS-33, 200 ohm/200 ohm, or equal); 4 μf-1500 v capacitor; and 220 ohm 2 watt resistor; or other suitable means for assuring dc isolation.

h. Rail clamps.

4. TEST SETUP AND PROCEDURE

4.1 Test Setup for Data Collection

The test setup for data collection shall be as shown in Figure RT/IE01A-1.

4.2 Procedure for Data Collection

This procedure shall be performed for each different operating mode of the rail transit vehicle, e.g., each different propulsion setting, and each different brake rate that the vehicle can be operated in, with the objective of obtaining worst-case data.

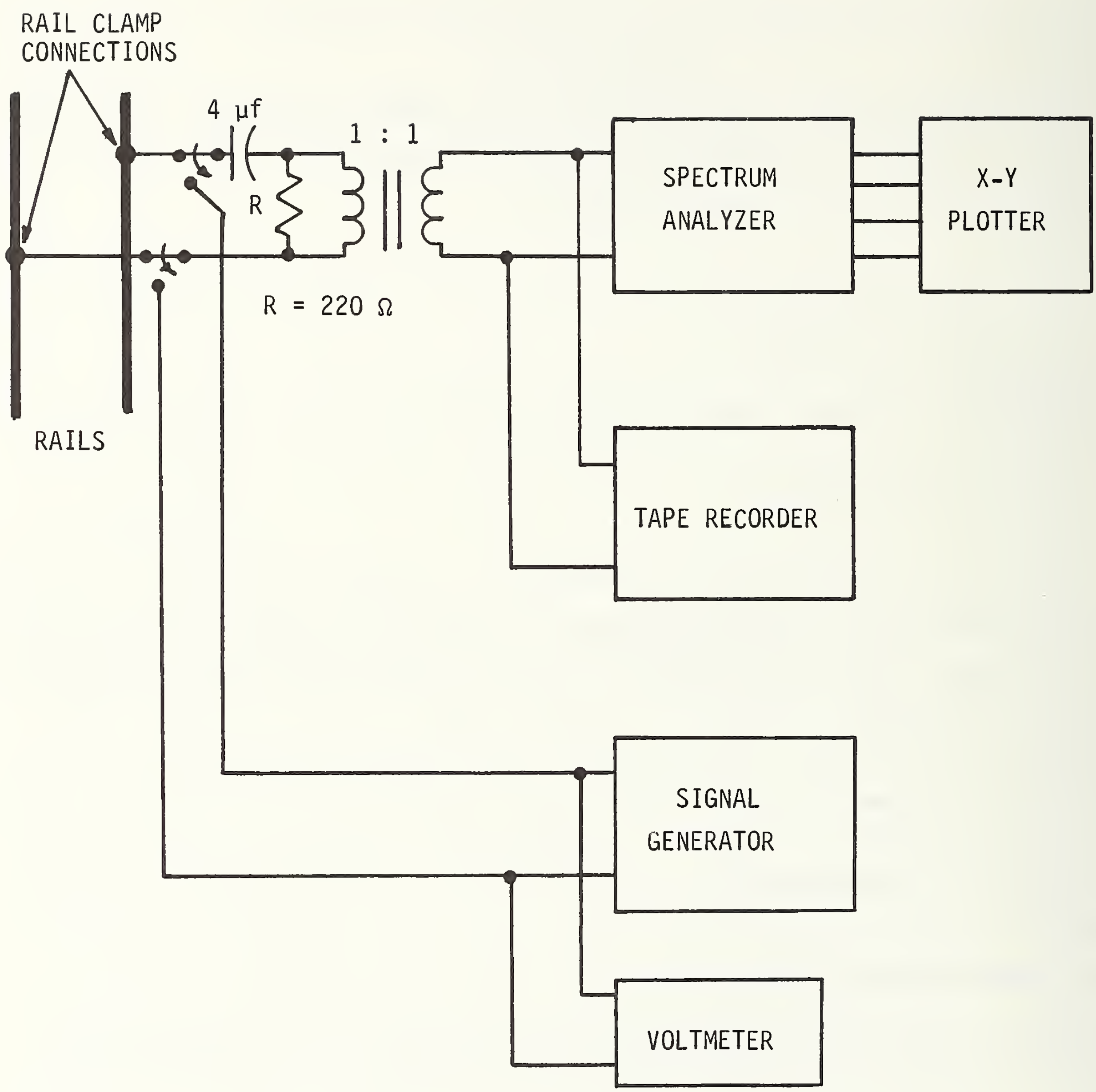


FIGURE RT/IE01A-1. TEST SETUP FOR DATA COLLECTION

4.2.1 Initial Preparation of the Spectrum Analyzer

Select the "Max. Hold" averaging mode, the Hann windowing mode, 10 db/division display, 0 dbv sensitivity, and linear frequency scale. Select the appropriate frequency range.

4.2.2 Calibration

Perform a calibration sweep covering the frequency range of interest as follows: Set up the equipment as shown in Fig. RT/IE01A-1, but attach the track coupling circuit input to the output of the audio-frequency signal generator rather than to the rails. Adjust the spectrum analyzer as noted in 4.2.1. Tape-record the signal into the spectrum analyzer. Using a fixed signal amplitude in the range of expected signal levels, step the frequency across the entire frequency range of interest. Each step must be of sufficient duration for the corresponding amplitude displayed on the spectrum analyzer to reach a steady final value. Make an X-Y plot of the final spectrum analyzer display. Note on the plot the signal amplitude, expressed in dbv, displayed on the spectrum analyzer at each frequency step. This amplitude is defined as $X_{odb}(f)$. Calculate the dbv value of the audio-frequency signal generator output, defined as X_{idb}. Then calculate, tabulate, and graph the instrumentation transfer function $H_{db}(f) = X_{odb}(f) - X_{idb}$. Values of $H_{db}(f)$ may be either greater than or less than 0. This transfer function characterizes the behavior of the system comprised of the track coupling circuit and spectrum analyzer.

Some spectrum analyzers, including the one specified herein (Item 3.0-a), do not correct automatically for the reduction in displayed amplitude occurring from use of the Hann window. In that event, the values of $H_{db}(f)$ determined above will include a term of -1.8 db amplitude due to Hann windowing. For other spectrum analyzers, refer to the value of Hann window correction factor stated by the manufacturer.

4.2.3 Performance of Test

With rail clamps attached to the rails, turn on the tape recorder, activate the spectrum analyzer, and have the vehicle run past the observation point. When the vehicle is clear of the observation point, store the spectrum analyzer display.

NOTE: If the spectrum analyzer's input signal overdrive indicator remained off during the passage of the vehicle, the data are valid. If the input signal overdrive indicator flashed or remained on during the vehicle's passage, change the sensitivity setting to +10 dbv and repeat 4.2.3. If overdrive indicator fails to remain off, change sensitivity setting to +20 dbv and repeat 4.2.3. If further desensitization is required, change transformer taps to achieve the required voltage reduction, and repeat 4.2.1-4.2.3. Use the voice channel of the tape recorder to record salient operating characteristics of the run, e.g., starting point or stopping point of train, propulsion or braking mode, and speed when the front of train reaches observation point.

4.2.4 Field Reduction of Data

With the display stored in the spectrum analyzer, move the frequency cursor across the spectrum analyzer screen and record the displayed dbv amplitudes of the peak values of harmonic components. If convenient, plot the spectrum analyzer display using the X-Y plotter. (It is recommended that X-Y plots be made in the field of some if not all runs, for later use in the lab in validating tape-recorded data.) Optionally, photograph the spectrum analyzer display. Using data from the graph of $H_{db}(f)$ from 4.2.2, subtract the corresponding values of $H_{db}(f)$ from displayed amplitude at each harmonic, to obtain the actual rail-to-rail dbv amplitude of each harmonic.

4.2.5 Test Repetition

Repeat 4.2.3 and 4.2.4 for each acceleration and braking mode. If a one-car train is used, multiple runs in each mode will be required to obtain data for the train passing the mesuring point at a variety of speeds.

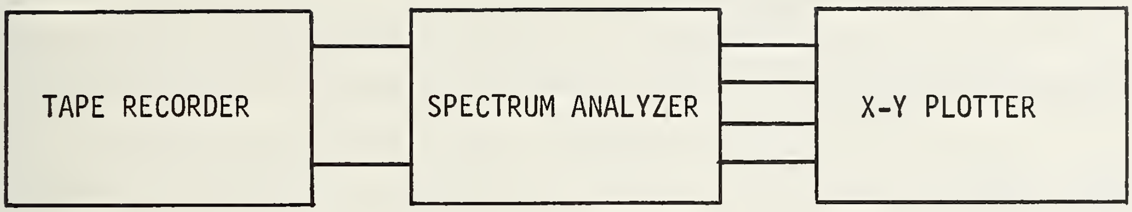


FIGURE RT/IE01A-2. TEST SETUP FOR LAB REDUCTION OF DATA

4.3 Laboratory Reduction of Data

4.3.1 Test Setup - The test setup shall be as shown in Figure RT/IE01A-2.

4.3.2 Calibration

Adjust the spectrum analyzer as noted in 4.2.1. Play back the calibration signals recorded in 4.2.2 into the spectrum analyzer. Using the tape recorder output as the stepped frequency source, repeat the remaining steps of 4.2.2, to obtain data for the overall instrumentation transfer function in both graphical and tabulated form, defined as $H'_{db}(f)$. This overall instrumentation transfer function will include characteristics of the track coupling network and spectrum analyzer as did $H_{db}(f)$, and in addition those of the tape recorder.

4.3.3 Data Reduction

Adjust the spectrum analyzer as described in 4.2.1. Play back the recorded interference signals into the spectrum analyzer, following procedures outlined in 4.2.3. Generate X-Y plots of displayed data as outlined in 4.2.4. To

calculate the actual rail-to-rail dbv amplitude of each harmonic, subtract the corresponding value of $H'_{db}(f)$ from each displayed harmonic amplitude. Compare the results of field data reduction and laboratory data reduction to verify the validity of the tape recorded data.

5. TABULATION OF RESULTS

5.1 Index of Runs

An index shall be prepared, giving pertinent information of each run, with runs numbered consecutively.

5.2 Tape Recordings

The tape recordings shall be stored for future use and analysis, along with a written index of tape contents, in the form of tape distance indications for various runs. The tape recorder used to make recordings shall be noted by make, model, and serial number.

5.3 Spectrum Analyzer X-Y Plots

X-Y plots of spectrum analyzer displays generated in the field according to 4.2.4 and in the lab according to 4.3.3 shall be numbered by run and stored in a permanent manner.

5.4 Spectrum Analyzer Photographs

Spectrum analyzer photographs taken in the field as noted in 4.2.4 shall be numbered by run and stored in a permanent manner.

6. NOTES

6.1 Recorded Rail-to-Rail Voltage

The recorded rail-to-rail voltage is equivalent to an open-circuit source voltage, and is the Thevenin equivalent source voltage of the rail-axle loop. The Thevenin equivalent source impedance of this loop is formed by the impedances of the rails, wheels, and axles. Observation of this voltage does not account for a voltage drop that would occur if actual track circuitry were connected between the rails. Such connection would allow current to flow through the source impedance and track circuit impedance in series, resulting in voltage division. The resulting voltage drop can be significant, depending on the relative values of track circuit impedance and source impedance.

REFERENCES

1. F.R. Holmstrom, "Inductive Interference in Rapid Transit Signaling Systems - Volume I: Theory and Background", DOT Report No. UMTA-MA-06-0153-85-7, U.S. Dept. of Transportation, Transportation Systems Center, Cambridge, MA 02142, January 1986.

2. "Inductive Interference in Rapid Transit Signaling Systems - Volume II: Suggested Test Procedures", DOT Report No. UMTA-MA-06-0153-85-8, U.S. Dept. of Transportation, Transportation Systems Center, Cambridge, MA 02142, <u>to be published</u>.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1986--700-476--30,131

150 copies

artment
portation

ch and
Programs
stration

are
Massachusetts 02142